ULDB
Systems
Definition
Review

ULDB Balloon Vehicle and Recovery Systems

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ULDB Vehicle and Recovery Systems

- Vehicle Structure
  - Main Envelope
  - Special Structural Elements
- Flight Trajectory Control Systems
  - Altitude Control
  - Ground Track Control
- Recovery Systems
  - Descent Element
  - Impact/Containment Elements
- Flight Train
  - Load Support/ Separation
  - Torque Transfer

Vehicle Structure

•Functional Requirements

Loft and maintain 'ballooncraft' , recovery system, and other support elements for up to 100 days Non-Polar

Achieve minimum float altitudes of 33.5 km to 35 km

•Target Design-to Requirements

Suspended Science Weight to 1000 kg

Total Suspended Weight to 1600 kg

Minimum Float Altitude >= 35 km

Balloon Vehicle Alternatives

- **"Brainstormed" Vehicle Ideas and Approaches**

  Initial categorization of concepts

- **Candidate Pool Narrowing**

  Completed at several different times and levels based on merit and applicability to Demo 2000 flight

- **Alternatives Reviewed**

  Superpressure Design
  Radiative Structure
  Multiple Balloons
  Lifting Gas Replenishment
  Tethered Balloon
  "Ballast" Collection
  Ballast Balloon
  Shape Variation

  Numerous other "creative" ideas/approaches

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Balloon
Vehicle

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Vehicle Trade Study Approach

- **Develop Initial Assumptions**

Payload Mass | *Material Radiative Properties*
Altitude | *Areal Density*
Free Lift | *Superheat*

Environment and Atmosphere

Radiative Environment, Ambient Temperature, Float Density, and Lapse Rate

- **Selection of Reference Vehicle Design**

Detailed Trade of "Historical" Superpressure Design

- **Compare Other Design Approaches to Reference**

Determine if approach offers advantage over reference design as a stand alone approach or if it can be used in conjunction to improve/enhance the design

Initial Assumptions

Payload Mass:

1364 kg (3,000 lbs) low
1591 kg (3,500 lbs) medium
1818 kg (4,000 lbs) high

Areal Density:

$0.0339\ N/m^2$ ($1\ oz/yd^2$)
$0.0509\ N/m^2$ ($1.5\ oz/yd^2$)
$0.0678\ N/m^2$ ($2\ oz/yd^2$)

Altitude:

35 km (115,000 ft)

Radiative Properties:

α/ε = 0.1, 0.2, and 0.3

Free Lift: 12 % and 20 %

Superheat: -5 % Night 20 % Day

Atmosphere:

Ambient Temperature 236.2 K
Lapse rate 0.73 km/K
Float Density $0.00849\ kg/m^3$

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Balloon Vehicle

Assumed Environments

Bounding Case	Solar Constant	Albedo	Earth Surface Temperature
Hot Case, Maximum Expected	1403.47 W/m2	0.55	50 C
Hot Case, Nominal “Over Water” Day	1403.47 W/m2	0.4	30 C
Cold Case, Nominal “Over Water” Night	0 W/m2	0	-2 C
Cold Case, Minimum Expected	0 W/m2	0	-90 C

- Hot Case, Maximum Expected
  Daytime, very hot desert, and high albedo
- Hot Case, Nominal “Over Water” Day
  Daytime, warm ocean, and high water albedo
- Cold Case, Nominal “Over Water” Night
  Nighttime with cold water surface
- Cold Case, Minimum Expected
  Nighttime with very cold cloud deck

Conversions

All figures are shown in metric units

1 m = 3.2808 ft

1 m^2 = 10.7639 ft^2

1 m^3 = 35.3134 ft^3

1 kg = 2.2046 lb

1000 N/m = 5.71 lb/in

0.0339 N/m^2 = 1 oz/yd^2

"Historical" Superpressure Design

- Spherical Shape
- Fabrication Factor of 1.15

  Includes weight of seams, fittings, accessories, and load introduction

- Material "Safety" Factor of 1.0

  Trades designed to determine the maximum material strength requirement for envelope.

  Safety factor will be applied during design of the balloon

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Trade Studies

Temperature Change vs a/e
Superheat vs a/e
Superheat Ratio vs a/e
Strength, a/e, Areal Density, and Payload Weight
Areal Density vs System Mass
Stress vs Superheat
Stress vs Free Lift (12% Superheat)
Stress vs Free Lift (20% Superheat)
Stress vs Superpressure
Balloon Volume vs Maximum Altitude
Superheat vs Actual Temperature

Tethered Balloon

Approach

- *Maintain balloon over one location via a tether from the ground*

Concerns

- *High strength low weight tether*
- *Winching*

Summary

- *Reasonably achievable tether strength to weight unobtainable*
- *Winch development significant*

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Radiative Structure

Approach

Vary balloons radiative property via cap or "curtain" to reduce the temperature change

Concerns

Added system mass

Limited reduction in strength requirement for significant a/e reduction

"Curtain" greatly increases system complexity

Summary

Not viable as a stand alone approach, but may provide envelope shielding to prevent UV degradation

"Ballast" Collection

Approach

Onboard system to "collect ballast" during day and expel at night

Concerns

Ambient air density very low

Power consumption high

Summary

Not a viable approach due to ambient atmospheric density

Multiple Balloons

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Approach

Use multiple structures to provide lift. Smaller balloons have lower material strength requirement and a lower "risk"

Concerns

System complexity

Mission and Operations issues

Weight penalty

Summary

Structures are still very large. Viable when a one balloon system will not satisfy the requirement.

Ballast Balloon

Approach

Two balloon system where one balloon is winched up and down to provide ballasting

Concerns

Complex launch and flight system

Tether strength and winch

Summary

Viable approach but significant risk in development for Demo 200 flight

Lifting Gas Replenishment

Reasons for Carrying Liquid Helium:

- *Allows reduction in required material strength through pressure reduction (venting) on rare, hot days, with subsequent gas makeup.*
- *Provides makeup for higher than expected diffusion and leakage losses.*
- *Allows a measure of trajectory control by allowing altitude excursions through venting and makeup cycles (useful esp. at mission end).*
- *May provide a source of instrument cooling power at no power cost.*

Definition of Benefit:

- *Each kg of liquid helium carried is equivalent to over 6 kg of lift.*
- *Small replenishment system weights will be on the order of 2 ½ to 3 times that of the helium carried, but improve dramatically with larger dewar volumes.*
- *Example: A 1000 liter (125 kg of liquid helium) system will provide 780 kg of lift, and will weigh on the order of 375 kg.*

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Balloon Vehicle

Shape Variation

Approach

1) *Vary balloon shape to reduce "thermal" loading*

2) Vary constructed shape (lobing) to reduce material strength requirement

Concerns

1) *Complex balloon pointing requirement*

2) New fabrication technique

Summary

Superpressure structure that includes lobing could significantly reduce material strength requirement

System Enhancements

Many of the reviewed approaches can be applicable for enhancing the flight performance

Radiative Cap

Lowered a/e and/or a/e ratio to reduce material strength requirement

UV degradation shielding

Shape Variation

Lobing could reduce material strength requirement

Gas Replenishment

Applicable but with significant weight penalty

Proposed Design Approach

- Superpressure design
  - *Volume ~ 0.6 MCM*
  - *Estimated Max Material Strength ~ 5,300 N/m*
  - *DP6611 material as baseline*
- Nominally spherical with slight shape modification for load introduction
- System enhancement options (by PDR)
  - *Lobed structure*
  - *Radiaitve cap*

Flight Trajectory Control Systems

- **Altitude Control**

  Numerous "creative" ideas/approaches proposed

  Anchor Balloon   Gas Replenishment   "Mass" Collection

  Pressure Control   Gas Temperature Control

- **Ground Track Control**

  Numerous "creative" ideas/approaches proposed

  Drag Chutes   Drag Lines   Propellers   Propulsion

- **Applicability**

  Approaches identified for both Altitude and Ground Track Control had significant weight and power penalties

  Limited applicability for Demo 2000 flight

Flight Train

•Functional Requirements

Support Gondola Load and Provide Balloon/Gondola Separation

•Target Design-to Requirements

Total Suspended Weight to 1600 kg

Torsional Stiffness TBD

Reduce Terminate Shock Load to <= 3g's

•Design Approach

"Standard" Flight Train to Mitigate Risk

Use In-Line Energy Absorption (see Recovery Systems)

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Summary and Recommendation

- Superpressure balloon design
  - *Volume ~ 0.6 MCM*
  - *DP6611 material as baseline*
- Potential for improving design
  - *Cap for reducing temperature variation and UV degredation protection*
  - *Lobing to reduce material strength requirement*
- No ground track or trajectory control
- Use “standard” flight train